

# Spinor field realizations of the non-critical $W_{2,4}$ string based on the linear $W_{1,2,4}$ algebra \*

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## Abstract

In this paper, we investigate the spinor field realizations of the  $W_{2,4}$  algebra, making use of the fact that the  $W_{2,4}$  algebra can be linearized through the addition of a spin-1 current. And then the nilpotent BRST charges of the spinor non-critical  $W_{2,4}$  string were built with these realizations.

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## I. INTRODUCTION

As is well known, tentative extensions of string-theory based on extra bosonic symmetry ( $W$ -symmetry) on the worldsheet are called  $W$ -strings. The theories on  $W$  algebra or  $W$  string have found remarkable applications since their discoveries [1, 2], they appear in  $W$  gravity, the quantum Hall effect, black holes, lattice models of statistical mechanics at criticality, membrane theories and other physical models [3] and so on.

The BRST charge of  $W_3$  string was first constructed in [4], and the detailed studies of it can be found in [4, 5, 6]. From these researches it appears that the BRST method has turned out to be rather fruitful in the study of the critical and non-critical  $W$  string theories [7]. A natural generalization of the  $W_3$  string, i.e. the  $W_{2,s}$  strings, is a higher-spin string with local spin-2 and spin- $s$  symmetries on the world-sheet. Much work has been carried out on the scalar field realizations of  $W_{2,s}$  strings [6, 8, 9], and the BRST charges for such theories have been constructed for  $s = 4, 5, 6, 7$  [8]. Later in Ref. [10] we pointed out the reason that the scalar BRST charge is difficult to be generalized to a general  $W_N$  string. At the same time, we found the methods to construct the spinor field realizations of  $W_{2,s}$  strings and  $W_N$  strings [10, 11]. Subsequently, we studied the exact spinor field realizations of  $W_{2,s}$  ( $s = 3, 4, 5, 6$ ) strings and  $W_N$  ( $N = 4, 5, 6$ ) strings [10, 11, 12]. Recently, the authors have constructed the nilpotent BRST charges of non-critical  $W_{2,s}$  ( $s = 3, 4$ ) strings with two-spinor field [13]. The results show that there exists a solution for the  $W_{2,4}$  string but no solution for the  $W_{2,3}$  case. These results will be of importance for constructing super  $W$  strings, and they will provide the essential ingredients.

However, all of these theories about the  $W_{2,s}$  strings mentioned above are based on the non-linear  $W_{2,s}$  algebras. Because of the intrinsic nonlinearity of the  $W_{2,s}$  algebras, their study is a more difficult task compared to linear algebras. Fortunately, it has been shown that certain  $W$  algebras can be linearized by the inclusion of a spin-1 current. This provides a way of obtaining new realizations of the  $W_{2,s}$  algebras. Such new realizations were constructed for the purpose of building the corresponding scalar  $W_{2,s}$  strings [14]. With the method, we have reconsidered the realizations of the non-critical  $W_3$  string in Ref. [15], and found that there exists a solution of four-spinor field realization. In this paper, we will go on to construct the nilpotent BRST charges of spinor non-critical  $W_{2,4}$  string by using the linear bases of the  $W_{1,2,4}$  algebra. Our results show that there exists a two-spinor field

realization for non-critical  $W_{2,4}$  string, which is just the same as the result in Ref. [15]. All these results will be of importance for embedding of the Virasoro string into the  $W_{2,4}$  string.

This paper is organized as follows. In section II, the method for constructing the BRST charge of non-critical  $W_{2,4}$  string is given. In section III, we first construct the linear bases of the  $W_{1,2,4}$  algebra with multi-spinor fields, then use these linear bases to construct the non-linear bases of the  $W_{2,4}$  algebra and give the spinor realizations of them. Finally, a brief conclusion is given.

## II. BRST CHARGE OF NON-CRITICAL $W_{2,4}$ STRING

The non-critical  $W_{2,4}$  string is the theories of  $W_{2,4}$  gravity coupled to a matter system on which the  $W_{2,4}$  algebra is realized. Now we give the spinor field realizations of them.

The BRST charge takes the form:

$$Q_B = Q_0 + Q_1, \quad (1)$$

$$Q_0 = \oint dz c(T^{eff} + T_\psi + T_M + KT_{bc} + yT_{\beta\gamma}), \quad (2)$$

$$Q_1 = \oint dz \gamma F(\psi, \beta, \gamma, T_M, W_M), \quad (3)$$

where  $K, y$  are pending constants and the operator  $F(\psi, \beta, \gamma)$  has spin  $s$  and ghost number zero. The energy-momentum tensors in (2) are given by

$$T_\psi = -\frac{1}{2}\partial\psi\psi, \quad (4)$$

$$T_{\beta\gamma} = 4\beta\partial\gamma + 3\partial\beta\gamma, \quad (5)$$

$$T_{bc} = 2b\partial c + \partial bc, \quad (6)$$

$$T^{eff} = -\frac{1}{2}\eta_{\mu\nu}\partial Y^\mu Y^\nu, \quad (7)$$

and the matter currents  $T_M$  and  $W_M$ , which have spin 2 and 4 respectively, generate the  $W_{2,4}$  algebra. The BRST charge generalizes the one for the scalar non-critical  $W_{2,4}$  string, and it is also graded with  $Q_0^2 = Q_1^2 = \{Q_0, Q_1\} = 0$ . Again the first condition is satisfied for  $s = 4$ , and the remaining two conditions determine the coefficients of the terms in  $F(\psi, \beta, \gamma, T_M, W_M)$  and  $y$ .

The most extensive combinations of  $F$  in Eq. (3) with correct spin and ghost number

can be constructed as following:

$$\begin{aligned}
F = & g_1\beta^4\gamma^4 + g_2(\partial\beta)^2\gamma^2 + g_3\beta^3\gamma^2\partial\gamma + g_4\beta^2(\partial\gamma)^2 \\
& + g_5\beta^2\gamma^2\partial\psi\psi + g_6\partial\beta\gamma\partial\psi\psi + g_7\beta\partial\gamma\partial\psi\psi \\
& + g_8\beta\partial^2\beta\gamma^2 + g_9\partial^2\beta\partial\gamma + g_{10}\partial\beta\partial^2\gamma + g_{11}\partial^2\psi\partial\psi \\
& + g_{12}\beta\partial^3\gamma + g_{13}\partial^3\psi\psi + g_{14}\partial\beta\gamma T_M + g_{15}\beta\partial\gamma T_M \\
& + g_{16}\partial\psi\psi T_M + g_{17}\beta\gamma\partial T_M + g_{18}T_M^2 \\
& + g_{19}\partial^2 T_M + g_{20}W_M.
\end{aligned} \tag{8}$$

Substituting (8) back into Eq. (3) and imposing the nilpotency conditions  $Q_1^2 = \{Q_0, Q_1\} = 0$ , we can determine  $y$  and  $g_i (i = 1, 2, \dots, 20)$ . They correspond to three sets of solutions, which had been given in Ref. [13] and we don't list them here again.

In order to build the spinor non-critical  $W_{2,4}$  string theory, we need the explicit construction for the matter currents  $T_M$  and  $W_M$ . In Ref. [13], we had given the realization of them directly by the OPE relations of non-linear  $W_{2,4}$  algebra. In the following section, we will reconstruct the non-linear bases  $T_M$  and  $W_M$  of  $W_{2,4}$  algebra by means of the linear bases  $T_0$ ,  $J_0$  and  $W_0$  of  $W_{1,2,4}$  algebra, making use of the fact that the  $W_{2,4}$  algebra can be linearized through the addition of a spin-1 current.

### III. CONSTRUCTIONS OF THE NON-LINEAR BASES OF $W_{2,4}$ ALGEBRA

#### A. Constructions of the linear bases of $W_{1,2,4}$ algebra

We begin by reviewing the linearization of the  $W_{2,4}$  algebra by the inclusion of a spin-1 current [16]. The linearized  $W_{1,2,4}$  algebra take the form:

$$\begin{aligned}
T_0(z)T_0(\omega) & \sim \frac{C/2}{(z-w)^4} + \frac{2T_0(\omega)}{(z-\omega)^2} + \frac{\partial T_0(\omega)}{z-\omega}, \\
T_0(z)W_0(\omega) & \sim \frac{4W_0(\omega)}{(z-\omega)^2} + \frac{\partial W_0(\omega)}{z-\omega}, \\
T_0(z)J_0(\omega) & \sim \frac{C_1}{(z-w)^3} + \frac{J_0(\omega)}{(z-\omega)^2} + \frac{\partial J_0(\omega)}{z-\omega}, \\
J_0(z)J_0(\omega) & \sim \frac{-1}{(z-\omega)^2}, \\
J_0(z)W_0(\omega) & \sim \frac{hW_0(\omega)}{z-\omega}, \quad W_0(z)W_0(\omega) \sim 0,
\end{aligned} \tag{9}$$

where the coefficients  $C$ ,  $C_1$  and  $h$  are given by

$$C = 86 + 30t^2 + \frac{60}{t^2}, \quad C_1 = -3t - \frac{4}{t}, \quad h = t. \quad (10)$$

To obtain the realizations for the linearized  $W_{1,2,4}$  algebra, we use the multi-spinor fields  $\psi^\mu$ , which have spin 1/2 and satisfy the OPE

$$\psi^\mu(z)\psi^\nu(\omega) \sim -\frac{1}{z-\omega}\delta^{\mu\nu}, \quad (11)$$

to construct the linear bases of them. The general forms of these linear bases can be taken as follows:

$$T_0 = -\frac{1}{2}\partial\psi^\mu\psi^\mu, \quad J_0 = \alpha_{\mu\nu}\psi^\mu\psi^\nu (\mu < \nu), \quad W_0 = 0, \quad (12)$$

where  $\alpha_{\mu\nu}$  are pending coefficients. By making use of the OPE  $J_0(z)J_0(\omega)$  in (9), we can get the equation that the coefficients  $\alpha_{\mu\nu}$  satisfy, i.e.  $\sum_{\mu<\nu}\alpha_{\mu\nu}^2 = 1$ . From the OPE relation of  $T_0$  and  $J_0$ , it is easy to get  $C_1 = 0$ . Substituting the value of  $C_1$  into Eq. (10), we can get the value of  $t$ . Then the total central charge  $C$  for  $T_0$  can be obtained from Eq. (10). So we can determine the explicit form of  $T_0$  under the restricted condition of its central charge. Finally, using the OPE  $T_0(z)J_0(\omega)$  in (9) again, we get the exact form of  $J_0$ . The complete results are listed as follows:

$$t = \pm\frac{2}{\sqrt{3}}i, \quad C = 1, \quad C_1 = 0, \quad (13)$$

$$T_0 = -\frac{1}{2}\sum_{\mu=1}^2\partial\psi^\mu\psi^\mu, \quad J_0 = \pm\psi^1\psi^2, \quad W_0 = 0. \quad (14)$$

## B. Spinor realizations of the $W_{2,4}$ algebra based on the linear $W_{1,2,4}$ algebra

Now let us consider the spinor realizations of the non-linear  $W_{2,4}$  algebra with linear bases of the  $W_{1,2,4}$  algebra. In conformal OPE language the  $W_{2,s}$  algebra takes the following forms:

$$T(z)T(\omega) \sim \frac{C/2}{(z-w)^4} + \frac{2T(\omega)}{(z-\omega)^2} + \frac{\partial T(\omega)}{(z-\omega)}, \quad (15)$$

$$T(z)W(\omega) \sim \frac{sW(\omega)}{(z-\omega)^2} + \frac{\partial W(\omega)}{(z-\omega)}, \quad (16)$$

$$W(z)W(\omega) \sim \frac{C/s}{(z-w)^{2s}} + \sum_{\alpha}\frac{P_{\alpha}(\omega)}{(z-\omega)^{\alpha+1}}, \quad (17)$$

in which  $P_\alpha(\omega)$  are polynomials in the primary fields  $W$ ,  $T$  and their derivatives. For an exact  $s$ , the precise form of  $W$  and the corresponding central charge  $C$  can be solved by means of these OPEs. The OPE  $W(z)W(\omega)$  for  $W_{2,4}$  algebra takes the form [17]:

$$\begin{aligned}
W(z)W(\omega) \sim & \frac{C/4}{(z-\omega)^8} + \frac{2T}{(z-\omega)^6} + \frac{\partial T}{(z-\omega)^5} \\
& + \frac{3}{10} \frac{\partial^2 T}{(z-\omega)^4} + \frac{b_1 U}{(z-\omega)^4} + \frac{b_2 W}{(z-\omega)^4} \\
& + \frac{1}{15} \frac{\partial^3 T}{(z-\omega)^3} + \frac{1}{2} \frac{b_1 \partial U}{(z-\omega)^3} + \frac{1}{2} \frac{b_2 \partial W}{(z-\omega)^3} \\
& + \frac{1}{84} \frac{\partial^4 T}{(z-\omega)^2} + \frac{5}{36} \frac{b_1 \partial^2 U}{(z-\omega)^2} + \frac{5}{36} \frac{b_2 \partial^2 W}{(z-\omega)^2} \\
& + \frac{b_3 G}{(z-\omega)^2} + \frac{b_4 A}{(z-\omega)^2} + \frac{b_5 B}{(z-\omega)^2} \\
& + \frac{1}{560} \frac{\partial^5 T}{(z-\omega)} + \frac{1}{36} \frac{b_1 \partial^3 U}{(z-\omega)} + \frac{1}{36} \frac{b_2 \partial^3 W}{(z-\omega)} \\
& + \frac{1}{2} \frac{b_3 \partial G}{(z-\omega)} + \frac{1}{2} \frac{b_4 \partial A}{(z-\omega)} + \frac{1}{2} \frac{b_5 \partial B}{(z-\omega)},
\end{aligned} \tag{18}$$

where the composites  $U$  (spin 4), and  $G$ ,  $A$  and  $B$  (all spin 6), are defined by

$$\begin{aligned}
U &= (TT) - \frac{3}{10} \partial^2 T, \\
G &= (\partial^2 TT) - \partial(\partial TT) + \frac{2}{9} \partial^2 (TT) - \frac{1}{42} \partial^4 T, \\
A &= (TU) - \frac{1}{6} \partial^2 U, \quad B = (TW) - \frac{1}{6} \partial^2 W,
\end{aligned}$$

with normal ordering of products of currents understood. The coefficients  $b_1, b_2, b_3, b_4$  and  $b_5$  are given by

$$\begin{aligned}
b_1 &= \frac{42}{5C+22}, \\
b_2 &= \sqrt{\frac{54(C+24)(C^2-172C+196)}{(5C+22)(7C+68)(2C-1)}}, \\
b_3 &= \frac{3(19C-524)}{10(7C+68)(2C-1)}, \\
b_4 &= \frac{24(72C+13)}{(5C+22)(7C+68)(2C-1)}, \\
b_5 &= \frac{28}{3(C+24)} b_2.
\end{aligned}$$

The bases of the  $W_{2,4}$  algebra can be constructed by the linear bases of the  $W_{1,2,4}$  algebra:

$$T = T_0, \quad W = W_0 + W_R(J_0, T_0), \tag{19}$$

where the currents  $T_0$ ,  $W_0$  and  $J_0$  generate the  $W_{1,2,4}$  algebra and have been constructed with multi-spinor fields in Eq. (14). First we can write down the most general possible structure of  $W$ . Then the relations of above OPEs of  $T$  and  $W$  determine the coefficients of the terms in  $W$ . Finally, substituting these coefficients and  $T_0$ ,  $J_0$  and  $W_0$  which have been constructed in section II into the expressions of  $T$  and  $W$ , we can get the spinor realizations of the  $W_{2,4}$  algebra. The explicit results turn out to be very simple as follows:

$$T = T_0, \tag{20}$$

$$\begin{aligned} W = & W_0 + \eta_1 \partial^3 J_0 + \eta_2 \partial^2 J_0 J_0 + \eta_3 (\partial J_0)^2 \\ & + \eta_4 \partial J_0 (J_0)^2 + \eta_5 (J_0)^4 + \eta_6 \partial^2 T_0 + \eta_7 (T_0)^2 \\ & + \eta_8 \partial T_0 J_0 + \eta_9 T_0 \partial J_0 + \eta_{10} T_0 (J_0)^2, \end{aligned} \tag{21}$$

where

$$\begin{aligned} \eta_1 &= \eta_0 (1800 + 5562t^2 + 7744t^4 + 6167t^6 \\ &\quad + 2631t^8 + 450t^{10}), \\ \eta_2 &= 12\eta_0 t (450 + 1278t^2 + 1429t^4 + 752t^6 + 150t^8), \\ \eta_3 &= 6\eta_0 t (1050 + 2932t^2 + 3009t^4 + 1353t^6 + 225t^8), \\ \eta_4 &= 12\eta_0 t^2 (4 + 3t^2) (150 + 226t^2 + 75t^4), \\ \eta_5 &= 6\eta_0 t^3 (150 + 226t^2 + 75t^4), \\ \eta_6 &= 3\eta_0 t (240 + 724t^2 + 865t^4 + 465t^6 + 90t^8), \\ \eta_7 &= 6\eta_0 t^3 (3 + t^2) (32 + 27t^2), \\ \eta_8 &= 12\eta_0 t^2 (150 + 376t^2 + 301t^4 + 75t^6), \\ \eta_9 &= 12\eta_0 t^2 (300 + 602t^2 + 376t^4 + 75t^6), \\ \eta_{10} &= 12\eta_0 t^3 (150 + 226t^2 + 75t^4), \\ \eta_0 &= -(36t + 12t^3)^{-1} (504000 + 3037560t^2 + 7617488t^4 \\ &\quad + 10300470t^6 + 8109196t^8 + 3716751t^{10} \\ &\quad + 918585t^{12} + 94500t^{14})^{-1/2}. \end{aligned}$$

Making use of the values of  $t$  in Eq. (13), we can get the simple form of  $W$  as follows:

$$W = W_0 + \frac{\sqrt{2}}{360} \left( \mp 54i\partial^3 J_0 + 198\sqrt{3}\partial^2 J_0 J_0 + 27\sqrt{3}(\partial J_0)^2 - 108\sqrt{3}(J_0)^4 + 12\sqrt{3}\partial^2 T_0 - 40\sqrt{3}(T_0)^2 \mp 108i\partial T_0 J_0 \pm 216iT_0\partial J_0 - 216\sqrt{3}T_0(J_0)^2 \right). \quad (22)$$

Substituting the expressions of  $T_0$ ,  $J_0$  and  $W_0$  in Eq. (14) into Eqs. (20) and (22), we immediately obtain the explicit constructions of  $T$  and  $W$  for the  $W_{2,4}$  algebra as follows:

$$T = -\frac{1}{2} (\partial\psi^1\psi^1 + \partial\psi^2\psi^2), \quad (23)$$

$$W = \frac{1}{72\sqrt{6}} (\partial^3\psi^1\psi^1 - 9\partial^2\psi^1\partial\psi^1 + 84\partial\psi^1\psi^1\partial\psi^2\psi^2 + \partial^3\psi^2\psi^2 - 9\partial^2\psi^2\partial\psi^2). \quad (24)$$

This result is just the same as that given in Ref. [13]. But the result here is obtained from the method based on linearized algebra. Substituting the form (8) of  $F$  into (3), with  $T_M$  and  $W_M$  given by Eqs. (23) and (24) respectively, we get the exact spinor field realizations of the non-critical  $W_{2,4}$  string.

#### IV. CONCLUSION

In this paper, we have reconstructed the spinor field realizations of the non-critical  $W_{2,4}$  string, making use of the fact that the  $W_{2,4}$  algebra can be linearized through the addition of a spin-1 current. First, the construction for the BRST charge of non-critical  $W_{2,4}$  string is given. Subsequently, we use the multi-spinor fields  $\psi^\mu$  to construct the linear bases of the linearized  $W_{1,2,4}$  algebra. Finally, the non-linear bases of  $W_{2,4}$  algebra is constructed with these linear bases  $T_0$ ,  $J_0$  and  $W_0$ . Thus, the spinor field realizations of the non-critical  $W_{2,4}$  string are obtained, and the result is the same as that of our previous work [13]. It is worth pointing out that the fields which give the realizations of the non-critical  $W_{2,4}$  string are two-spinor, while the fields corresponding to the non-critical  $W_{2,3}$  string are four-spinor. The reason is that, the total central charges  $C$  of  $T_0$  for  $W_{1,2,3}$  algebra and  $W_{1,2,4}$  algebra are 2 and 1, respectively, and the central charge for any term  $-(1/2)\partial\psi^\mu\psi^\mu$  in  $T_0$  is 1/2. Compared with the results of Ref. [18], in which the BRST charge of non-critical  $W_{2,4}$  string is constructed by ghost fields, the realizations of spinor fields in this paper are more

simple. It is very clear that the spinor realizations of the critical  $W_{2,4}$  string can be obtained when the matter currents  $T_M$  and  $W_M$  in Eqs. (2) and (3) vanish, and the corresponding constructions become relatively simple. We expect that there should exist such realizations for the case of higher spin  $s$ .

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- [1] A.B. Zamolodchikov, *Theor. Math. Phys.* **65** (1985) 1205.
- [2] V.A. Fateev and A.B. Zamolodchikov, *Nucl. Phys.* **B280** (1987) 644.
- [3] A.N. Leznov and M.V. Saveliev, *Acta Appl. Math.* **16** (1989) 1, and references therein; L. Feher, L.O 'Raifeataigh, P. Ruelle, et al., *Phys. Rep.* **222** (1992) 1, and references therein.
- [4] J. Thierry-Mieg, *Phys. Lett.* **B197** (1987) 368.
- [5] C.N. Pope, L.J. Romans, E. Sezgin and K.S. Stelle, *Phys. Lett.* **B2748** (1992) 29; F. Bais, P. Bouwknegt, M. Surridge and K. Schoutens, *Nucl. Phys.* **B385** (1988) 99.
- [6] H. Lu, C.N. Pope, S. Schrans and K.W. Xu, *Nucl. Phys.* **B385** (1992) 99; H. Lu, C.N. Pope, S. Schrans and X.J. Wang, *Nucl. Phys.* **B408** (1993) 3.
- [7] C. Becchi, A. Rouet and R. Stora, *Phys. Lett.* **B52** (1974) 344; I.V. Tyutin, Lebedev preprint No. **39** (1975), unpublished.
- [8] H. Lu, C.N. Pope, X.J. Wang and S.C. Zhao, *Class. Quantum. Grav.* **11** (1994) 939; H. Lu, C.N. Pope, X.J. Wang and S.C. Zhao, *Phys. Lett.* **B327** (1994) 241.
- [9] M. Bershadsky, W. Lerche, D. Nemeschansky and N.P. Warner, *Phys. Lett.* **B292** (1992) 35; *Nucl. Phys.* **B401** (1993) 304; E. Bergshoeff, A. Sevrin and X. Shen, *Phys. Lett.* **B296** (1992) 95.
- [10] S.C. Zhao and H. Wei, *Phys. Lett.* **B486** (2000) 212.
- [11] S.C. Zhao, H. Wei and L.J. Zhang, *Phys. Lett.* **B499** (2001) 200.

- [12] S.C. Zhao, L.J. Zhang and H. Wei, *Phys. Rev.* **D64** (2001) 046010; S.C. Zhao, L.J. Zhang and Y.X. Liu, *Commun. Theor. Phys.* **41** (2004) 235.
- [13] Y.S. Duan, Y.X. Liu and L.J. Zhang, *Nucl. Phys.* **B699** (2004) 174.
- [14] H. Lu, C.N. Pope, K.S. Stelle and K.W. Xu, *Phys. Lett.* **B351** (1995) 179; F. Bastianelli and N. Ohta, *Phys. Lett.* **B348** (1995) 411.
- [15] L.J. Zhang, Y.X. Liu and J.R. Ren, *New Spinor Field Realizations of the Non-Critical  $W_3$  String*, to appear in Chinese Physics Letters [hep-th/0507265].
- [16] S.O. Krivonos and A.S. Sorin, *Phys. Lett.* **B335** (1994) 45; S. Bellucci, S.O. Krivonos and A.S. Sorin, *Phys. Lett.* **B347** (1995) 260.
- [17] R. Blumenhagen, M. Flohr, A. Klemm, W. Nahm, A. Recknagel and R. Varnhagen, *Nucl. Phys.* **B361** (1991) 255; H.G. Kausch and G.M.T. Watts, *Nucl. Phys.* **B354** (1991) 740.
- [18] Y.X. Liu, L.J. Zhang and J.R. Ren, *JHEP* **0501** (2005) 005.
- [19] K. Thielemans, *Int. J. Mod. Phys.* **C2** (1991) 787.